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A Decision Analysis of an Oil Company's Retail Strategy in the Face of Electric Vehicle Penetration Uncertainty

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A Decision Analysis of an Oil Company's Retail Strategy in the Face of Electric Vehicle Penetration Uncertainty

by

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Abstract

A Decision Analysis of an Oil Company's Retail Strategy in the Face of Electric Vehicle Penetration Uncertainty

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The University of Texas at Austin, 2012

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This thesis evaluates emerging electric vehicle technology and estimates what effect it might have on how an oil company decides on its gas station network. It is conducted using data from South Korea, a country poised for a fast adoption of electric vehicles. The study first reviews the literature to gather reasonable cases of electric vehicle penetration. Also, after researching technology-diffusion theories, the study selects a model that can well explain the literature review data. The scenarios induced by this function are utilized as the main uncertainties confronting an oil company's network decision model. Based on a probabilistic simulation, the study finds that the effects of technology diffusion alter the priority order of an oil company's network decision alternatives. Namely, after the overall uncertainty level rises, directly owning gas station, with its heavy initial investment, is not preferred for an oil company's network strategy. From the result, the study also estimates the scale of the new technology's effect. Such effect is found to be significant enough to alter a part of an oil company's retail strategy.

Nevertheless, such effect cannot be shown to be so great as to change the current retail oil market structures.

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1. Introduction

Just like any other sector, the petroleum retail industry has passed through uncertain market environments. What oil companies consider as the main causes of uncertainty are oil prices and the related retail margin. These go through significant and unpredictable fluctuations. If we put aside, however, the uncertainty about oil prices, this market has been, up to now, relatively stable. If we compared it to, say, the electronic devices industry, we would see much greater changes in the profit structures of market participants. The relative steadiness of the retail oil market results from steady demand and the mild competition among oil companies in the market.

Recently, however, signs suggest a coming change to this established market environment. Some of the signs are new transportation technologies and possible new market entrants. It is uncertain whether these factors are a sign of a structural market change or just a passing trend. It is certain, however, that these new trends raise the uncertainty level in the oil retail market. Confronted with this fact, oil companies are in need of a reasonable model that is able to manage these new uncertainties. Particularly if they are drawing up a long-term investment plan, for example buying new gas stations, they need to be able to calculate their expected revenue and assess their potential risk. Such companies should make it a priority to closely evaluate the potential of these new market trends.

This study first explains the current competition structure of the retail oil market; it then defines the threats oil companies will face in the future. After reviewing the related literature, this study develops possible future scenarios based on factors of uncertainty. Bearing these uncertainties in mind, the study constructs a probabilistic decision model for an example oil company's network investment. Oil companies, as a result of this study, should be able to have an idea of how to respond elastically to mid- or long-term market changes. Because it is impossible to accurately predict the future, we believe that logic and a framework of rational analysis are more important than a specific data set. Although this model cannot produce an absolute solution, it can produce an optimized strategy at a specific moment with up to date information and proper decision-making procedures.

2. Background

This paper begins with a brief introduction of the retail oil market in South Korea (referred to hereafter as “Korea”). It then discusses the general factors of electric vehicles (EVs), which were examined as a key driver of structural change in the retail oil market.

2.1 Korean Retail Oil Market

The goal of this study is to develop a general analysis frame that can, with minimal variable adjustments, be applied to any other country’s retail oil market. It focuses, however, on Korean market. The Korean market has several interesting characteristics. These include having a high level of energy consumption while lacking any domestic oil reserves, an influential government, the relative competiveness of alternative fuels and vehicle technologies. These factors, we believe, make Korea potentially susceptible to structural changes in the transportation sector in the near future. As with those of other countries, Korea's retail oil market has, over its history, developed its own unique form. The following sections will explain these characteristics according to the classification of market structure, demand, and price.

2.1.1 Market Structure

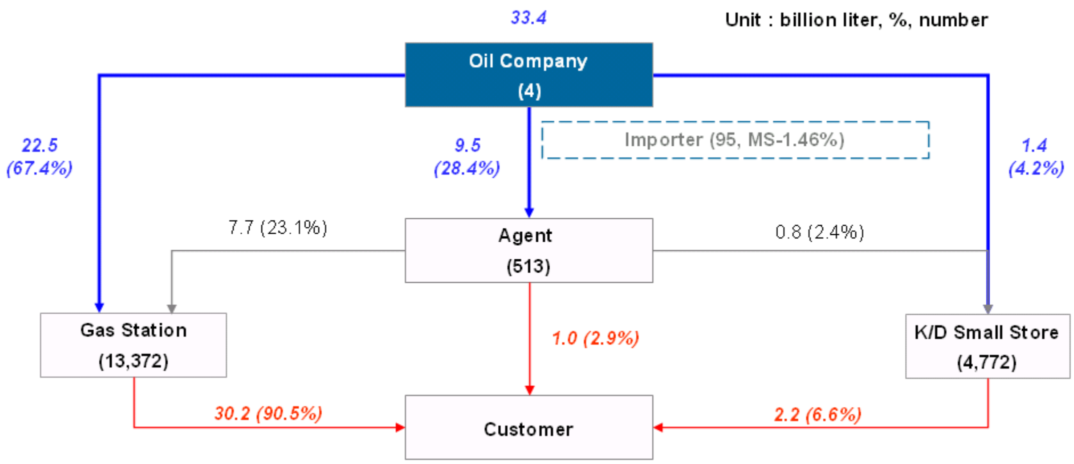

Figure 1: Distribution Channel Structure (MKE, 2009)

Korea has four major oil companies—SK Innovation, GS Caltex, S-Oil, and Hyundai Oilbank. One unique feature of Korea's market is the absence of any global brands; some global brands, however, do hold shares of Korean oil companies. Chevron owns 50% of GS Caltex's shares and AOC (Aramco Overseas Company) owns a 35% stake in S-oil. Korea's four major oil companies control 98.5% of Korean domestic oil distribution. SK Innovation occupies the biggest portion of domestic sales with 29.3% of market share. They are followed by GS Caltex with 25.1% (in 2008). Korea does import from 95 registered importers, but these provide only a small amount of diesel and kerosene; in 2008, their market share was only 1.46% (MKE, 2009).

Also in 2008, registered agents numbered 513. Agents are a kind of wholesale distributor, which compensates the oil companies' distribution channel through brand-using contracts with oil companies. They sell oil companies' products to other gas stations and through their own gas station networks. Agents supply 28.4% of the total clean product distribution, which includes gasoline, diesel, and kerosene in 2008 (MKE, 2009). Up to now, it has been hard to ignore the role of agents in the Korean retail oil market. However, their role seems to be shrinking. Gas stations are being managed by oil companies without the aid of agents. Furthermore, their numbers are increasing. The economics of agents operating gas station is worsening.

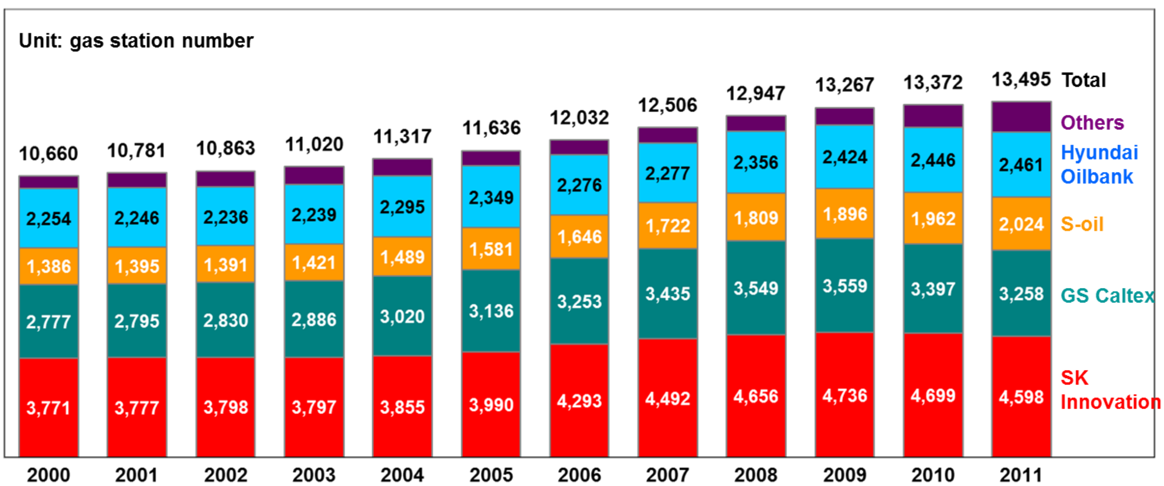

Figure 2: Gas Station Network Trend (KRA, 2012)

As mentioned, gas stations in Korea are on the rise. By the end of 2011, they totaled 13,495 (Figure 2). Korea's four major oil brands occupied 91.4% of all gas stations; the portion of these owned outright by oil companies was approximately 13.4% (KRA, 2012). Why the rise in these numbers? One reason is a stable domestic demand. Another is the continual rise in land prices (Figure 3). In spite of all this, unit sales volume and the economics of gas stations is only getting worse. It would seem then that, for at least the near future, the number of gas stations has reached its saturation point.

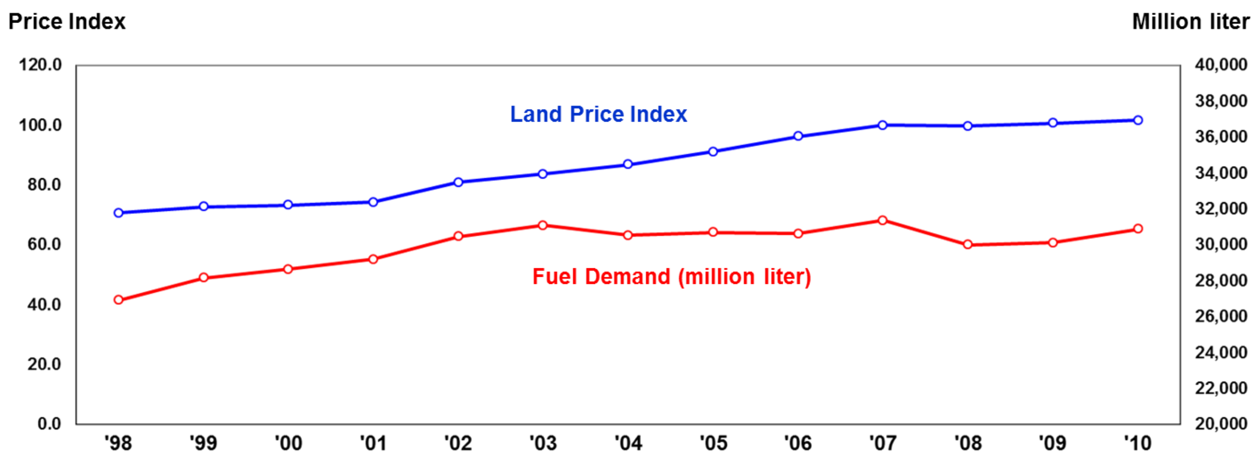

Figure 3: Land Price & Transportation Fuel Demand (Onnara and KNOC, 2012)

2.1.2 Demand

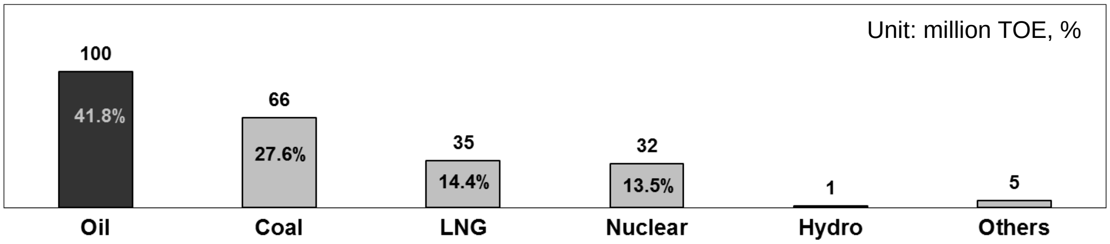

Figure 4: Primary Energy Consumption in Korea (MKE, 2009)

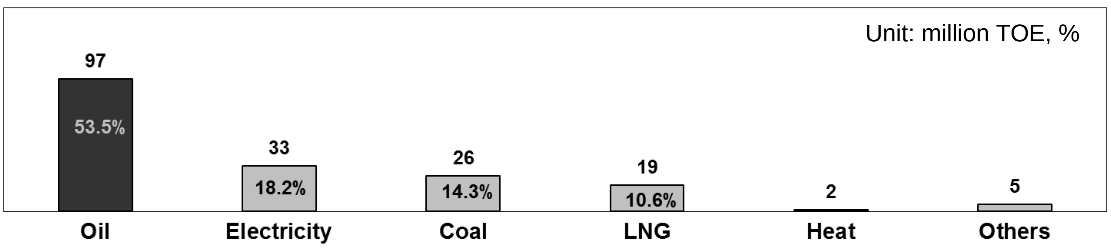

Figure 5: Secondary Energy Consumption in Korea (MKE, 2009)

As shown in Figures 4 and 5, in Korea, oil has maintained its position as the most important energy resource. Especially, in the transportation sector, oil's role is overwhelming. In 2011, gasoline and diesel vehicles made up 90.2% of the total registered cars (KAMA, 2012). The most significant feature of retail oil demand in Korea is its steadiness. Notwithstanding a dropping economic growth rate, the number of registered vehicles has steadily increased, averaging 3.9% growth annually (Figure 6).

Fuel demand in Korea has also shown a very inelastic pattern to price change. As shown in Figure 7, over the last five years, retail prices have fluctuated severely. However, demand for gasoline has been steady aside from some seasonal effects (KNOC, 2012).

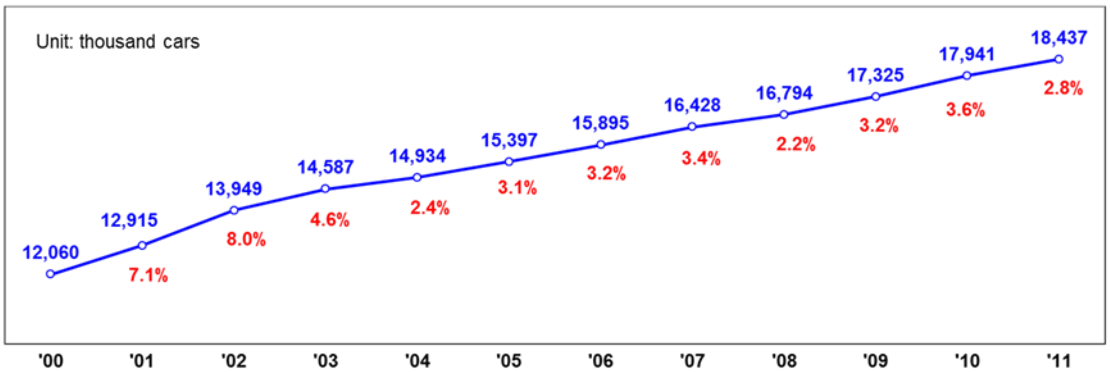

Figure 6: Registered Vehicles and Annual Growth Rate (KAMA, 2012)

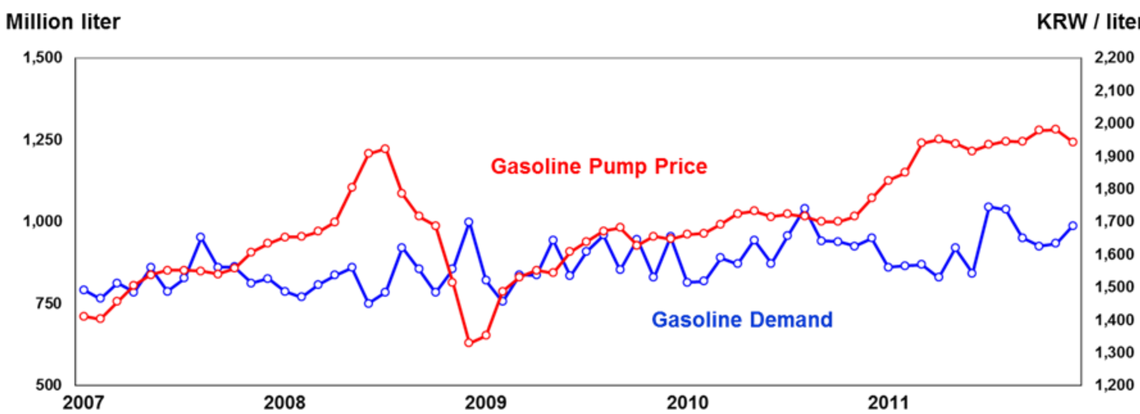

Figure 7: Monthly Demand and Retail Price Trend of Gasoline (KNOC, 2012)

2.1.3 Price

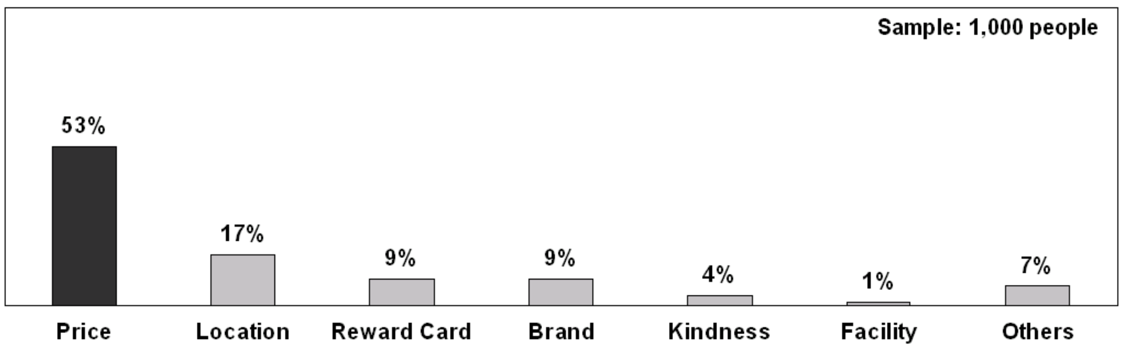

Figure 8: Gas Station Selecting Reasons (Kim, et al., 2010)

In step with economic growth, oil consumption per capita has increased. Nevertheless, Koreans have been unsettled by the relatively high retail prices. Not surprisingly, the majority of Koreans watch closely the daily fluctuations in oil price. Figure 8 shows the survey results of customers' gas-station-selecting behavior. For over half the consumers (53%), price was the most important criterion (Kim, et al., 2010).

Many factors influence the retail price-forming mechanism. Among these, the basic elements consist of crude price, international oil product price, taxes, and market competition. The pricing schemes of Korean oil companies are based on production and opportunity costs. Production costs are heavily influenced by crude oil prices. Opportunity costs are made up of international petroleum product prices. Although variations exist, about 39% of gasoline retail price is crude is (KNOC, 2012).

Korean oil companies' exports account for a significant portion of their total output. In 2010, they exported 36.4% of their production (KNOC, 2012). Because exports are another option for Korean oil companies' sales, the companies always compare the economics of the domestic and export market. When the domestic market is weaker than the international spot market, companies raise the export portion of their output. This explains why international oil product prices affect the opportunity cost for Korean oil companies. In the Asian oil market, Dubai crude and Singapore spot product prices are usually used as benchmark price indexes (IEEJ, 2010).

2.1.4 Issues about EVs diffusion

In Korea, the future of EVs looks bright. Korea's market-influential government is eagerly seeking energy security. Also, Korean companies are competitive in EV-related technologies: battery and vehicle. This is also an accelerating factor of EV diffusion.

2.1.4.1 Energy Security

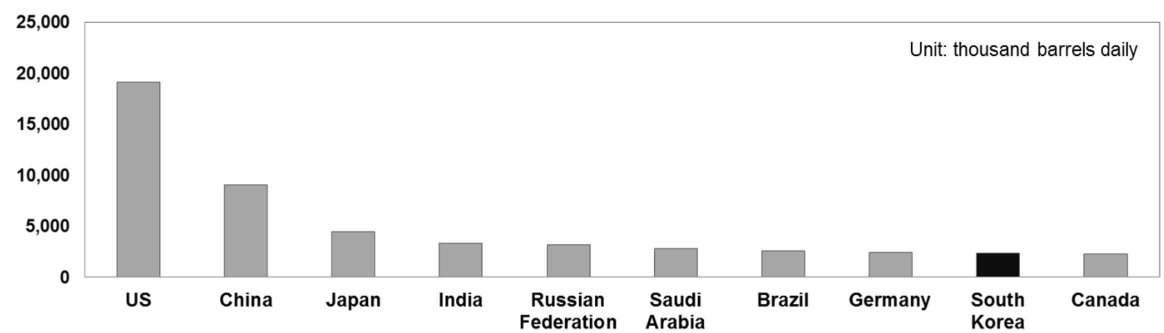

Figure 9: Oil Consumption Ranking by Countries (BP, 2012)

Korea ranks as the world's 9th largest oil-consuming country (Figure 9). Without a single oil reservoir, Korea depends entirely on imported oil to meet its oil demand. Therefore, energy security has always been the Korean government's main concern. It is the impetus behind the current administration's insistence that the country's future vision be "Low Carbon Green Growth" (Green Growth Committee, 2012). To help achieve its green vision, one of the government's core tasks is promoting EVs diffusion. Korean government considers EVs as more sustainable alternatives because coal and nuclear of which prices are relatively stable, explain 77% of electricity generation in Korea (MKE, 2009). The next section discusses this further.

2.1.4.2 Government's Role

In the Korean oil market, the most influential player is the government. The current administration endorses small government and has minimized, in most sectors, its intervention in the free market. The exception, of course, is the oil market. The government believes that energy is closely related to people's welfare. It can easily see the potential for a cartel forming among the major oil companies; this could, the government knows, hurt the quality of people's daily life. The policy goal of the Korean government concerning the retail oil market is to encourage competition through all distribution channels and to lower the market price level. The governments' policies about the retail oil market fall into three categories: invigorating competition between oil companies and importers, strengthening the negotiating power of independent gas stations with oil companies, and providing customers complete price information (MKE, 2009).

To encourage oil product imports, the Korean government keeps the tariff on oil products relatively low, as it does with the tariff on crude. Normally, governments impose higher tariffs on final products than on raw materials so as to protect domestic manufacturers. Hence, the import duty policy of the Korean government is rather exceptional. The government is also reviewing the relaxing of fuel specification standards, which acts as a barricade against foreign oil products.

The Korean government believes that oil companies, with their well-known brands, have a subjugating power over individual gas stations. They believe that the health or lack thereof of a certain oil company's brand can limit market competition. As a solution to this problem, they are encouraging the "double pole" gas station. A double pole gas station is simply one provided with oil from more than one oil company. The government expects such an arrangement to enhance the negotiating power of independent gas stations. Indeed, gas stations would have alternative options with more than one business partner.

Aside from these policies to encourage competition, the government continually tries fostering renewable technologies and alternative fuels. EV diffusion, as mentioned above, is one of its main policies. Table 1 shows the government's strategic target for EV diffusion. When we consider its strong influence on related industries, this target cannot be dismissed as just an unrealistic slogan.

Table 1: Korean Government's Policy Target for EV Diffusion (MKE, 2012)

- Starting small size EV mass production by 2011
- Expanding EV's share in small car market up to 10% by 2015
- Starting mid-size EV mass production by 2017
- Target market share of EV in 2020: 20% of total passenger vehicle
- Accumulated EV sales by 2020: 1 million vehicles

  (about 10% of total registered vehicles)

2.1.4.3 Technology Base

Concerning the development of EV technology, Korea has a strong industrial foundation. Korean battery companies and automakers continue to approach a competitive level in the global market. In 2011, Korean battery makers' global market share of lithium-ion battery was 39%, the largest portion among all competitors. The global market shares of Samsung SDI and LG Chemical were 23% and 16%, respectively (Figure 10). Also, Korea is home to the world's 5th largest automaker, Hyundai-Kia Motor (Automobile Produktion, 2012). Furthermore, many Korean companies are trying to enter EV recharger market. Of course, these factors alone are not grounds for predicting fast EV diffusion. They are, however, necessary conditions. As long as Korean companies continue to invest in related technologies, the potential grows for EV in Korea.

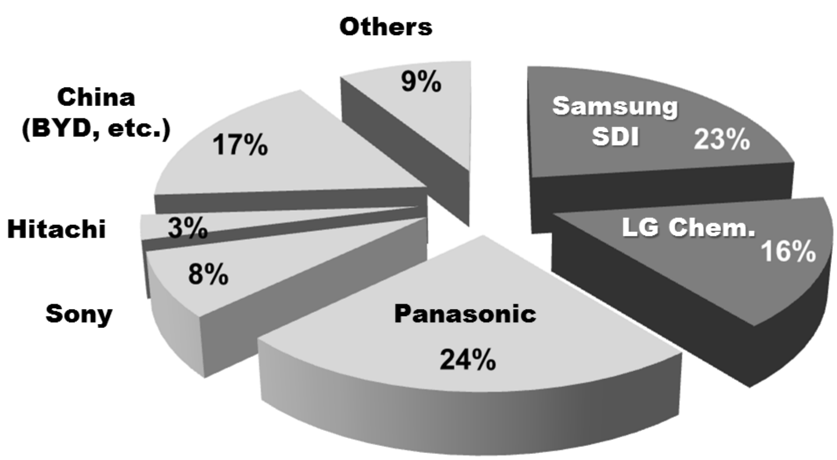

Figure 10: Global Lithium-ion Battery Market Share in 2011 (TSR, 2012)

2.1 ELECTRIC VEHICLES

EVs are considered to have significant potential. They could, it is believed, change the whole structure of the current oil retail market. Such potential is due to their potential oil displacement effect and to their unique refueling pattern. This section first defines the concept of electric vehicles and then provides a brief history of them. Lastly, it considers some characteristics of EVs that might serve as the catalyst that alters the structure of Korea's retail oil market.

2.2.1 Definition

Generally speaking, an electric vehicle (EV) is a type of vehicle powered, at least in part, by electricity (MIT Electric Vehicle Team, 2008). EVs come in three kinds—HEV (Hybrid Electric Vehicle), PHEV (Plug-In Hybrid Electric Vehicle), and BEV (Battery Electric Vehicle). Figure 11 shows the basic structure of each type of EV.

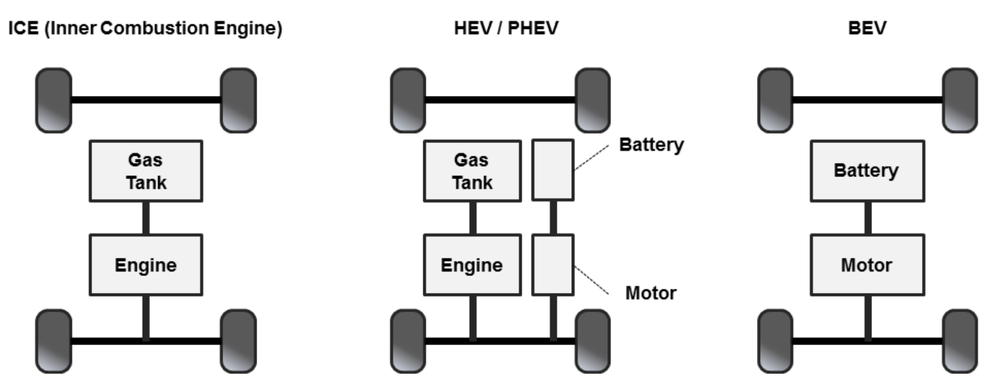

Figure 11: Structures of Electric Vehicles (Hori, 2004)

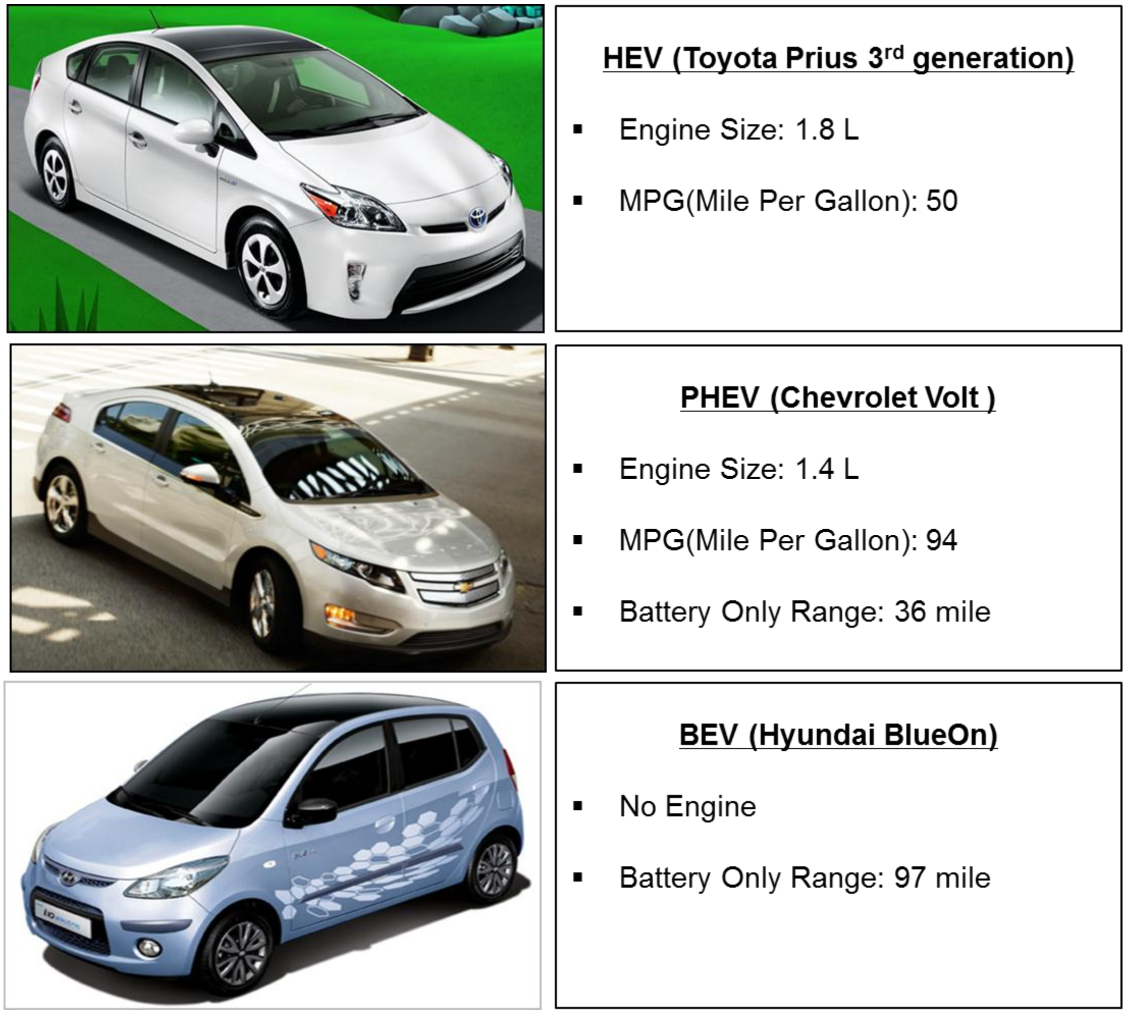

Figure 12: Examples of Electric Vehicles (Source: Toyota, Chevrolet, and Hyundai)

Regular inner combustion engine (ICE) vehicles get their mobility from gasoline or diesel fuel's chemical power. In contrast, EVs use electro-magnetic power as their main or ancillary propulsion power. HEVs use a battery and motor at a lower speed; they recharge during deceleration using kinetic energy loss. Two main differences distinguish HEVs from PHEVs: battery size and the possibility of external battery recharging. A PHEV's battery size is usually larger than that of an HEV. Therefore, it can drive farther solely on electric power. A PHEV can also draw electricity from an external power source both through normal and fast recharging equipment. Alternatively, a BEV functions solely on battery power. Its battery size is much larger than those of other types of electric vehicles (Hyundai Motors, 2012). Figure 12 shows representative examples of each electric vehicle type.

2.2.2 Brief History

The history of EVs is a long one. Its technology is older than even that of fossil fuel engine cars. The first BEV was invented in 1834. In 1898, Dr. Porsche in Germany built the first HEV. With the emergence of gasoline vehicles, however, EV technology was practically forgotten. It was not until the early 1990s that EVs returned to the fore. In 1990, CARB (the California Air Resource Board) of the United States passed a zero emission vehicle mandate. This policy compelled automakers to design new EVs and HEVs. During this time, several companies designed new EVs, including "EV1" by GM, "EV Ranger" by Ford, "EV Plus" by Honda, "Altra EV" by Nissan, and "RAV4 EV" by Toyota. Yet EVs failed to catch on. Ultimately, automakers scrapped all their EV models, all except Toyota, who retained its Prius, considered "the first modern HEV" and "the most successful HEV." After the first one was sold in Japan in 1997, the Prius's global sales in 2011 surpassed 2 million units (Anderson & Anderson, 2010).

Desire for alternative fuel technologies, including EVs, was recently reignited by a surge in oil prices. In 2010, Chevrolet introduced their first (PH)EV, the Volt (Chevrolet, 2012) and other automakers also began developing EV models. Hyundai Motors got in on this trend, unveiling in 2010 their first EV, the BlueOn (Hyundai Motors, 2012).

2.2.3 Issues

This part of the study considers three reasons why we should pay attention to (PH)EVs' potential to be a market changer. Namely, these reasons are its oil displacement effect, the attendant change to refueling infrastructures, and the potential margin shrinkage for oil companies. It also covers why (PH)EVs are important compared to other alternative fuels on the Korean market.

2.2.3.1 Oil Displacement Effect

If (PH)EVs hit their stride, their oil displacement effect could become significant. As noted already, HEVs and (PH)EVs' fuel efficiencies are much higher than normal ICE vehicles. Moreover, BEVs rely solely on battery energy, making its oil consumption zero. Of course, oil is consumed in electricity generation sector, but its portion is not large; relatively stable and abundant coal and nuclear explain the majority of electricity generation in Korea (Figure 13). The following section closely analyzes the scale of (PH)EVs' oil displacement by its market penetration rate. Indeed, the effect could be meaningful to an oil company's retail strategy.

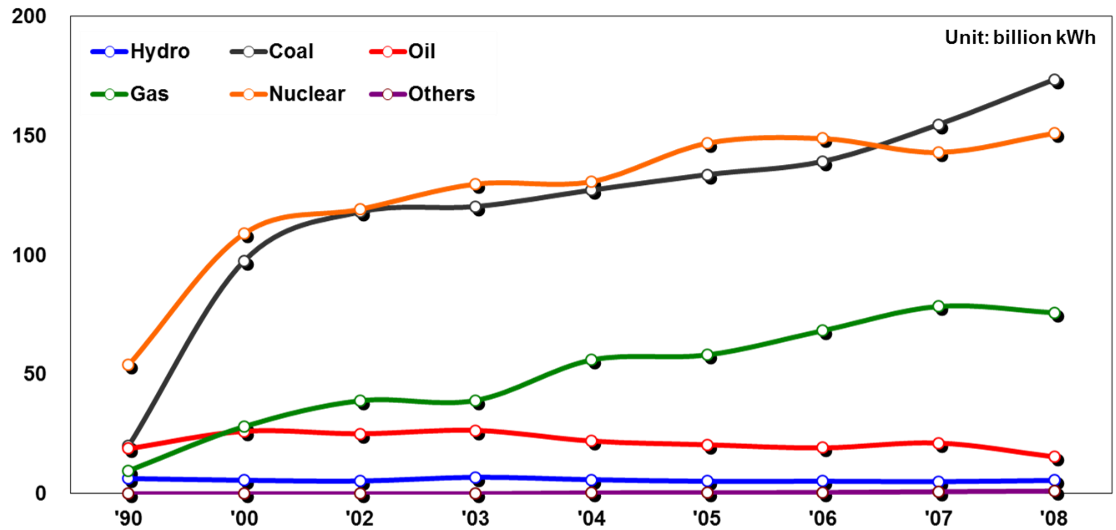

Figure 13: Electricity Generation Amounts in Korea by Sources (MKE, 2009)

2.2.3.2 Refueling Network Change

The differences between ICE refueling infrastructures and those of (PH)EV are huge. ICEs need dedicated places, gas stations. Gas stations need large storage space for fuel tanks, but they also need it for safety reasons. Gasoline and other petroleum products carry with them the risk of fire or explosion. Their leakage can seriously harm the environment. (PH)EV recharging, of course, can do without such special facilities. It needs merely a place where power line access is available.

(PH)EV recharging consists of two main types (see Figure 14). A car's battery can be recharged either from a normal or high voltage external power grid. Or it can be swapped with a fully charged one (Shukla, et al., 2011). This second type requires specialized sites, much like current gas station network. The first type, however, can be done at more various places with fast and normal speed recharging. For example, people can recharge their (PH)EVs in their own garages or in public parking lots, including street parking spaces. Should this type become the standard, it would seriously affect oil companies' network strategies. Oil companies want to expand their business domain to (PH)EV recharging at their current gas stations, yet their return would probably be insufficient since (PH)EVs have little reason to stop at gas stations and people may not want to waste their time for recharging there.

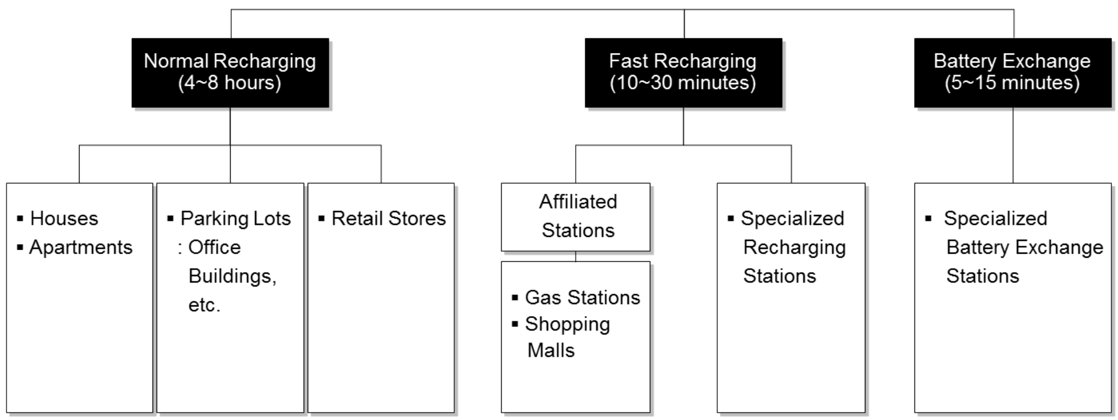

Figure 14: Possible EV Recharging Concept (MKE, 2012)

2.2.3.3 Oil Companies' Margin Structure Change

There is another reason that oil companies would fail to make a satisfactory profit recharging (PH)EVs. For oil companies, electricity is not a profitable product. Korean oil companies' main business domain is refining and distribution. Korea has a presence in exploration and production, but its portion is relatively minor. Concerning domestic sales, their margin structure can be seen in Figure 15.

Only in two stages can oil companies exploit a margin. The refining margin is collected in the crude cracking process; the marketing margin is collected in the sales of their oil products. In other words, in the Korean market, oil companies are producers and sellers of oil products. However, in a (PH)EV recharging market, this double profit structure disappears thanks to the government-owned, monopolistic electricity provider, KEPCO (Korea Electric Power Corporation). In (PH)EV recharging business, obviously, the production and wholesale margin goes to the electricity company. The oil companies running the (PH)EV recharging stations reap only the small retail margin.

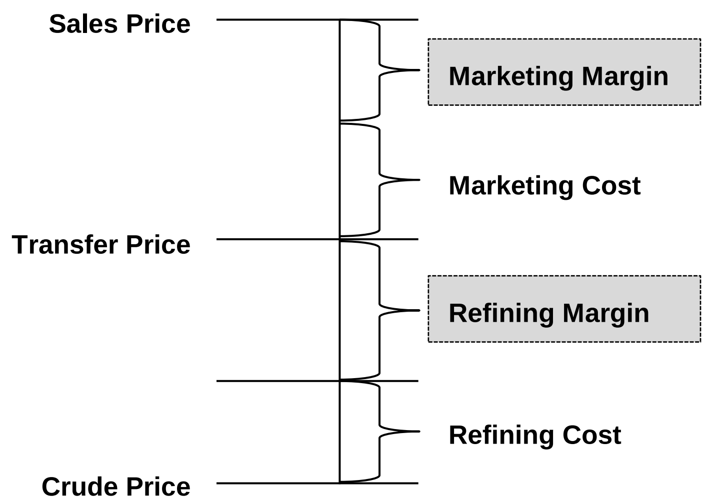

Figure 15: Simplified Margin Structure of Oil Companies in Korean Market

2.2.3.4 Comparison with Other Alternative Fuels

Several alternative fuel candidates exist besides EVs. Vehicles can run on natural gas, bio-fuel, and hydrogen fuel cells. These forms, however, are not this study's main concern and won't be treated with a detailed analysis. Generally, though, we can surmise that their influence will pale in comparison to that of (PH)EVs. Why? These fuels, in the Korean market, have low feasibility. Even if these fuels supplanted the position now held by oil, oil companies' profit loss would be much milder than should the same happen with (PH)EVs.

Most of the natural gas Korea consumes is imported as LNG (Liquefied Natural Gas). LNG is transported by vessels from the Middle East, Southeast Asia and other far flung regions. Therefore, its price in Korea is much higher than PNG (Pipeline Natural Gas) prices in other markets (MKE, 2009). Bio-fuel production costs in Korea are much higher than these fuels' competitors (KRA, 2012). Oil companies could enter into the bio-fuel production industry and, moreover, this liquid fuel still needs a gas station network. The threat of bio-fuels then is not serious to oil companies, even if we assume it is somehow economically feasible. Many researchers say that hydrogen fuel cell technology, at this point, is fraught with too many uncertainties. Therefore, we cannot evaluate its effect exactly, but just like bio-fuels, hydrogen fuel cell vehicles also require some kind of designated filling station for hydrogen recharging. So, we can reckon that the emergence of hydrogen fuel cells will not change the overall frame of Korea's gas station network (MKE, 2012).

3. (Plug-In) Hybrid Electric Vehicles' Market Penetration Scenarios

This chapter evaluates the future of (PH)EVs. This analysis will lead a formulating of their possible market penetration scenarios. For this analysis, data are gathered from the recent literature, which includes future (PH)EVs' market penetration scenarios. Furthermore, the study reviews technology-diffusion theories and then uses a selected model to generalize the literature review result about the market penetration rate of (PH)EVs.

3.1 Forecast Data in Relevant Literatures

After reviewing the literature, this study selected 25 recent reports, listed below in Table 2. Most of these focused on the United States' automotive market; some analyzed European and Japanese markets. No study could be found for the Korean market. From these studies, 61 future scenarios were extracted, each partially covering the period from 2008 to 2100. Each of these scenarios is plotted in the graph in Figure 16. Huge variations separate the studies' forecasts. This divergence mainly stems from their different assumptions about (PH)EV battery costs, gasoline prices, recharging infrastructure deployment levels, greenhouse gas emission regulations, government subsidies, and so forth.

Table 2: Literatures about (PH)EV Market Penetration Forecast

1. ORNL (2011) “A Comparative Study of Emerging Vehicle Technology Assessment”
2. EIA (2011) “Alternative to Traditional Transportation Fuel 2009”
3. EIA (2011) “Annual Energy Outlook”
4. IEA (2011) “Technology Roadmap: Electric and Plug-in Hybrid Electric Vehicles”
5. IEEJ (2010) “Oil Product Distribution and Price Forming Mechanism in Asian Market”
6. Deloitte (2010) “A Customer View of Electric Vehicles Mass Adoption in the U.S. 5. Automotive Market”
7. EPA (2010) “EPA Analysis of the Transportation Sector”
8. J.D. Power and Associates (2010) “Driven Green 2020: More Hope than Reality?”
9. Karplus et al. (2010) “Prospects for Plug-in Hybrid Electric Vehicles in the United States and Japan”
10. ORNL (2010) “PHEV Market Introduction Study”
11. JRC (2010) “Plug-in Hybrid and Battery Electric Vehicles: Market Penetration Scenarios of Electric Drive Vehicles”
12. BCG (2009) “The Comeback of the Electric Car?”

Table 2, cont.

13. University of Vermont (2009) “A Review of Results from Plug-in Hybrid Electric Vehicle Impact Studies”
14. ANL (2009) “Well-to-Wheels Energy Use and Greenhouse Gas Emission Analysis of 15. Plug-in Hybrid Electric Vehicles”
15. EVS-24 (2009) “Plug-in Hybrid Electric Vehicles: Promise, Issues and Prospects”
16. University of Michigan (2009) “Market Models for Predicting PHEV Adoption and Diffusion”
17. ANL (2009) “Impact of Real World Drive Cycles on PHEV Fuel Efficiency and Cost for Different Powertrain and Battery Characteristics”
18. Deutsche Bank (2008) “Electric Cars: Plugged In”
19. PNNL (2008) “Plug-in Hybrid Electric Vehicle Market Penetration Scenarios”
20. MIT (2008) “On the Road in 2035”
21. EPRI (2007) “Environmental Assessment of Plug-in Hybrid Electric Vehicles”
22. ANL (2007) “Impact of Component Size on Plug-in Hybrid Vehicle Energy Consumption Using Global Optimization”
23. PNNL (2007) “Impact Assessment of Plug-in Hybrid Vehicles on Electric Utilities and Regional U.S. Power Grids”
24. ORNL (2006) “Impact of Plug-in Hybrid Vehicles on the Electric Grid”
25. NRC (2010) “Transitions to Alternative Transportation Technologies – Plug-in Hybrid Electric Vehicles”

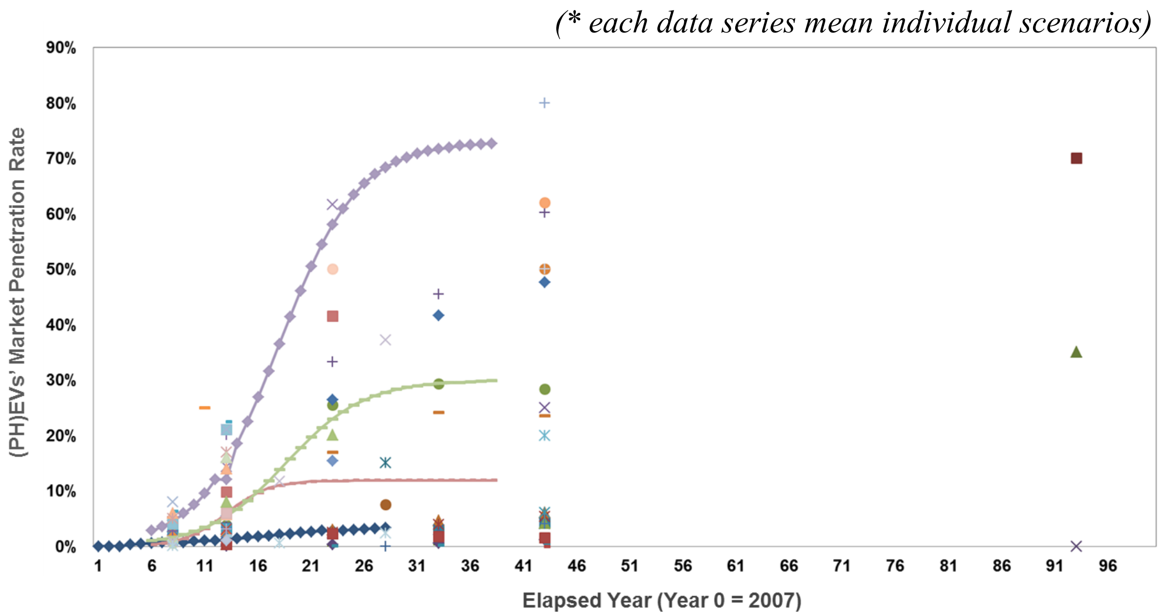

Figure 16: Recent Studies' Scenarios about (PH)EVs' Market Penetration

Most studies tried conducting sensitivity or what-if analyses about these factors. Some studies, for their model, used the survey results of customers and industry people. Oak Ridge National Laboratory's (ORNL) 2011 report is a comparative study of numerous studies on (PH)EV technology. This report analyzed 31 pieces of relevant material (Markel, et al., 2011). MIT's report, "On the Road in 2035" uses a scenario-planning method to explain the future penetration rates, in America and Europe, of advanced propulsion systems. The three scenarios in this report are: "The Market Mix-No Clear Winner Scenario," "The Turbocharged ICE Future Scenario," and "The Hybrid Strong Scenario." The report assumes that the market penetration of new technologies follow an S-shaped growth curve. It predicts that by 2045 they reach 50% of total new car sales (Bandivadekar, et al., 2008).

MIT produced another report in 2009, "Prospects for Plug-In Hybrid Electric Vehicles in the United States and Japan: A General Equilibrium Analysis." This report developed 24 scenarios of (PH)EV's market penetration with the "MIT EPPA" model. The outputs vary by (PH)EV markup price (15%/30%/80%), utility factor of model, and the existence of climate policies and biofuel use (Karplus, et al., 2010). Argonne National Laboratory's (ANL) 2009 study examines (PH)EV's lifetime cost saving with different assumptions. The major uncertainties in the model include discount rate, purchasing price differences from normal ICE, and gasoline prices. This report also uses these same uncertainties. ANL's report employs literature review data to set up its scenarios and to conduct "What-if" analysis. ORNL's 2010 study measures different policy options and their effect on (PH)EV's market adoption. It also projects cumulative (PH)EV sales according to different policy options.

The European Commission Joint Research Center (JRC) adopted four scenarios of (PH)EV and BEV diffusion in Europe's market. In their 2010 study, they combine the progression of battery price and the deployment of a recharging infrastructure. These scenarios assume that medium size BEVs are commercialized in 2015, and (PH)EV in 2020. In this report, the main criteria of customers' vehicle selection consist of four—initial vehicle price, fuel costs, autonomy range, and ease of access to recharging infrastructures. The model, which the current study also makes use of, uses these criteria to calculate the probabilities of each type of car selection (Nemry & Brons, 2010).

The report, "Plug-in Hybrid Electric Vehicle Market Penetration Scenarios" by Pacific Northwest National Laboratory (PNNL) develops three possible scenarios of (PH)EV technology diffusion. In its study, PNNL decided the market penetration rate of (PH)EV by reflecting industry experts' opinions, opinions that seem to be consistent with historical technology adoption rates (Balducci, 2008). Deloitte uses interview data from customers and related industry people to forecast the shape of the future EV market. Deloitte categorizes customer as early adopter, early majority, and non-adopters (Deloitte, 2010).

Roland Berger's report "Powertrain 2020" concerns the lithium-ion battery industry. According to this study, due to the increasing number of EVs, battery prices will drop significantly in the next 10 years (Roland Berger Strategy Consultants, 2010). Deutsche Bank conducted a comprehensive study about EV and related industries in its report, "Electric Cars: Plugged In." The report uses literature review data of EV's market penetration rate (Lache, et al., 2008). Boston Consulting Group's (BCG) report considers the total cost of ownership (TCO). TCO is the function of gasoline price as a major driver of (PH)EV adoption. BCG's report claims that EVs will be feasible only when battery prices drop below $500/kWh under $100~$120/bbl oil price (Book, et al., 2009).

According to EIA's "Annual Energy Outlook 2011," by 2035, (PH)EVs' sales will account for 3% of LDV sales in the United States (EIA, 2011). J.D. Power's "Driven Green 2020" provides the result of customer surveys and expert interviews about the hybrid and electric vehicle market. According to this report, a number of major hurdles stand between customers and widespread (PH)EV adoption. Setting aside future oil prices and environmental policies, these hurdles include the vehicle's limited driving range, the recharging infrastructure and recharging time, battery replacement cost, performance, and total ownership cost, i.e., car price, fuel and maintenance cost(Humphrey, et al., 2010).

3.2 TECHNOLOGY DIFFUSION THEORIES

Many studies used sensitivity analysis to define (PH)EVs' market penetration scenarios. Others tried to develop forecasting models with technology diffusion and adoption theories. A representative study on technology diffusion is Frank M. Bass' 1969 study. The author designed a so called "Bass Model" (Bass, 1969). His study focused on the behavior of customers' initial purchasing of certain merchandise. According to Bass, when a purchase of a certain product has not yet been made, the initial buying of that merchandise at time T can be made into the probability, $P(T) = p+q/m\ Y(T)$, where p and q/m are constant and Y(T) is the number of people who have already purchased the product. Bass defined the concepts of "innovator" and "imitator" by their buying behavior. The innovator cares nothing about the number of previous buyers; the imitator does. When making the buying decision about some product, the imitator is influenced by how many have already bought it.

With these concepts, in looking at the previous equation, we can think of p as the probability at T = 0 or the coefficient of "Innovation," q as the coefficient of "Imitation," and m as potential number of adopters. After some calculations, Bass expressed sales volume at time T as $S(T) = pm+(q-p)Y(T)-q/p(Y(T))^2$ and solved this equation like $Y(T) = m((1-\exp(-t(p+q))/(1+(p+q)\exp(-(p+q))))$. In his study, Bass tested this model with empirical data for 11 customer durables. He found this model could explain well the historical data (Bass, 1969). Later Bass developed a more generalized form of the model, the so called "the Generalized Bass Model" (Bass, et al., 1994). This new model combined the "current marketing effort" function with the simple Bass Model. With this new function, for example, the model is able to reflect price and cost effects.

Bass's studies contributed many implications to technology adoption and diffusion theory. Nevertheless, his models do have certain limitations. The major challenge with the Bass models is that they fail to explain very well the dynamics between initial purchase and replacement buying (Centrone, et al., 2007). The "Bass Model" and the "Generalized Bass Model" are based fundamentally on the premise of the customer's innovative and imitative behavior at their initial purchase. Hence, they can explain well the sales in the beginning phase of a new product. They are inadequate, however, for long-term forecasting purposes, which should include replacement purchasing behavior. Secondly, Bass models assume a fixed ultimate market potential of a product. In many cases, however, it is difficult to verify that saturation point exactly (McManus & Senter, 2009).

Some studies applied technology diffusion theories to help delineate (PH)EV's future sales. Centrone, et al developed a model that basically followed "the Bass Model," except for having unfixed ultimate potential sales volume (Centrone, et al., 2007). In this model, the number of potential adopters of (PH)EVs can be classified as the customers who have already bought (PH)EVs and those yet to adopt the technology. The populations of both types are defined as the function of time.

Struben and Sterman suggested a model that explains the dynamic of new sales, stock, and scrappage of (PH)EVs. This model focused on how households' managed their vehicle fleet (Struben & Sterman, 2008). A 2009 University of Michigan study was the first to examine several technology diffusion models including both models with a fixed saturation level (Bass, Generalized Bass, Logistic and Gompertz model) and models without (Centrone and the Consideration-Purchase Model). Their study, in verifying the coefficients of each model, analyzed historical (1999 to 2008) sales data of HEVs in the U.S. market for (McManus & Senter, 2009).

3.3 ANALYSIS

Any probabilistic decision model for an oil company's network decision, as with the one to be built and explained later, must include one of the main uncertainties—

(PH)EV's oil displacement effect. Forecasting the market penetration of (PH)EVs is an important step in calculating its oil displacement effect. This section employs meta-analysis of data from other studies and applies a logistic technology adoption model so as to develop representative market penetration scenarios of (PH)EVs.

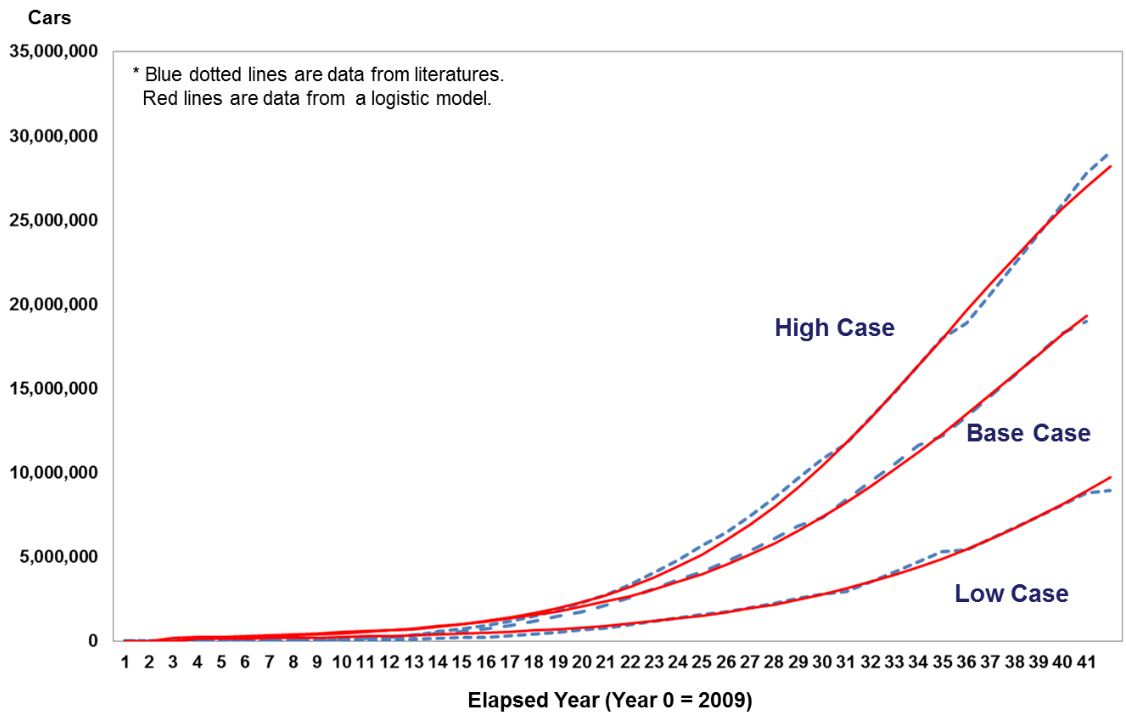

Figure 17: (PH)EVs' Market Penetration Scenarios

Figure 16 illustrates recent (PH)EV sales forecasts. Some studies provided actual numbers of vehicles and others offered ratios of market penetration. This graph, however, converts all the data into ratios. By Monte Carlo simulation of each data which is assigned to an individual year, we calculated for our samples the top and bottom 10% as well as the average value. Assuming we could apply these results to the Korean market, we can calculate the ratios back to the actual vehicle number for Korea. The (PH)EV penetration ratios from the literature was multiplied by future vehicle stock projection in Korea. This was made by regression analysis of historical data to get specific (PH)EV numbers for our predicting period. The blue dotted lines in Figure 17 show the result of this calculation.

As of now, no commercial (PH)EV sales record exists for Korea. Therefore, to define the coefficient of the (PH)EV diffusion model, this paper utilized as base data the projection results from the literature. The model employed for this study is the "Logistic Model," used by McManus & Senter Jr. (2009) to forecast (PH)EV sales in the United States market. Since this model is basically a logistic funtion, it lacks a logical foundation for forecasting the (PH)EV market. Also, it assumes a specific saturation point for sales. This is not good for explaining the longterm dynamic of customer behavior. For all that, this model has many advantages, especially considering the insufficient amount of empirical data. The model is simple and flexible. Therefore, it is easy to understand and can easily fit another data set. For this study, that is a particularly adequate characterisitc. In addition, since this study analyzes the beginning phase of a (PH)EV era, the assumption of a fixed saturation level matters little.

The solution of the logistic model can be experessed as Equation (1), where A(t) is the cumulative sum of adoption, L1 is market potential (saturation volume), L2 is slope parameter, and L3 is year-to-peak sales.

$$A(t) = \frac{L_1}{1 + \exp(-L_2(t - L_3))} \tag{1}$$

The data from the literature can be generalized by this model. In Figure 17, the red lines mean the data from the logistic model; with the base case assumptions, (PH)EVs' market penetration will reach, in 20 years, about 11%. The coefficient values chosen for each case are shown in Table 3.

Table 3: The Coefficients of the Logistic Model

Cases	**L_1 (potential sales volume: cars)**	**L_2 (slope parameter)**	**L_3 (year to peak sales: elapsed year)**
Low	30,000,000	0.133	34
Base	35,000,000	0.149	38
High	40,000,000	0.177	46

4. An Oil Company's Retail Strategy Analysis

This chapter finally analyzes how (PH)EV's oil displacement effect can change an oil company's retail strategies. Oil companies employ many strategies for their retail businesses. Product and promotion strategies as well as pricing, are important decision areas for the retail business. This study, however, focuses solely on the network strategy: obtaining new oil distribution channels and selecting operating systems for them. Little difference separates the qualities and production costs of each company's products. Thus, in Korea's oil retail market it is generally known that differentiation in pricing, product, and promotion is a challenge (MKE, 2012). Therefore, it is reasonable to suppose that the main strategic interest of an oil company concerns its network.

4.1 MODEL STRUCTURE

This study assumes a situation in which an imaginary Korean oil company is formulating a new network strategy. This hypothetical company can either buy new gas stations and manage them directly or make a supply contract with an independent dealer already owning the gas stations. In addition, this company can choose to sell its products to the domestic spot market with no investment.

This company's decision problem can be diagramed as seen in Figure 18. Such is an efficient method of visualizing the probabilistic relation among uncertain variables and decisions (Howard & Matheson, 2005). The decision node in Figure 18 contains the aforementioned alternatives. CC (Company Control) and DC (Dealer Control) relate to using gas stations. SPOT refers to the forgoing of gas stations and selling to the domestic SPOT market. The octagon shape represents the value node. The economics of each decision alternative will be evaluated by the net present value (NPV) over 20 years of the gas station's operating period.

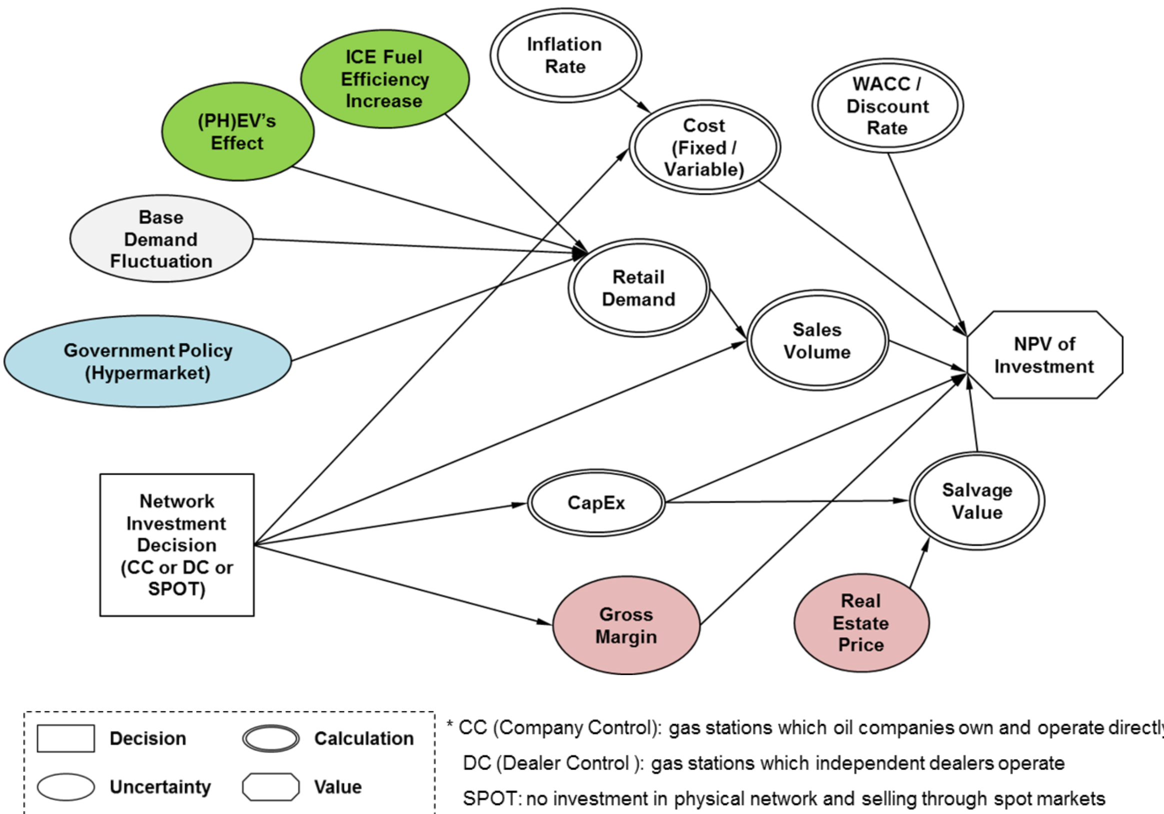

Figure 18: Decision Diagram

The analysis period was set by considering Korea's reconstruction cycle for gas station buildings (Seo & Kim, 2011). This model is fraught with major uncertainties. These include (PH)EVs' market penetration rate, ICE's fuel efficiency improvement, hypermarket gas stations, base demand change, retail margin fluctuation, and increases in land prices. As you can see in this figure, this model assumes that retail market demand is calculated by some uncertainties. Dependent on the market demand is the expected sales volume of decision options.

First, this study analyzes the best choice among this company's three decision alternatives. The analysis is based on the BAU (Business As Usual) which considers as uncertainties only the fluctuations in base demand, margin, and land price. Following this analysis, the study adds new uncertainties to the model, i.e., (PH)EVs' and other technologies' oil displacement effect and hypermarket gas stations' sales reduction. This study examines how strategic priorities change before and after these new uncertainties are considered. It also evaluates how much profit shrinks in each case.

4.2 DECISIONS

This model's major decision problem is selecting an optimum sales channel when a hypothetical oil company wants to expand its gas station network. Company Control (CC) is where the company invests in land and in gas station buildings and facilities. Once it obtains a gas station, the company is assumed to run it directly. Dealer Control (DC) is where the company opts out of direct investment, making instead a contract with an independent dealer already in possession of his own gas station. The contract guarantees a certain ratio of sales volume, and the oil company can now sell its products to this dealer. The sales volume is usually less than the CC scenario. In return for the secured sales volume, the company normally allows the dealer to use its brand, providing the dealer various marketing benefits. The oil company also occasionally loans money to the dealer for facilities and equipment purchase like dispensers.

If the oil company chooses the third option, SPOT, it sidesteps all these initial costs. Indeed, such an option requires no physical investments or marketing costs. The flip side of this is the company's expected gross margin is also much lower. In spot trading, the only consideration is price . Furthermore, the spot market is not currently a formally established sales channel. Hence, the company cannot always expect secured sales. Table 4 shows brief characteristic of the three alternatives.

Table 4: Three Decision Alternatives: CC, DC, and SPOT (Energy Media, 2012)

Alternatives	Major Characteristics
CC	▪ Type of gas station, which an oil company directly owns and operates ▪ 100% sales volume at this site belongs to the oil company. ▪ CC's gasoline portion of total sales volume is larger than other options. ▪ Usually, sales price is higher than at independent dealers' sites.
DC	▪ Type of gas station, owned and operated by an independent dealer. It uses a particular brand and provides that company's products up to a certain portion of their total sales volume (according to the contract with the oil company). ▪ Usually, the oil company cannot expect that their products make up 100% of the sales volume at this type of site. ▪ DC's average pump price is lower than CC's
SPOT	▪ The trade option of selling its product on the domestic spot market. ▪ No established spot market. Consequently, sales volume with the SPOT option cannot always be secured. ▪ The potential margin is lower than other two options.

4.3 UNCERTAINTIES

This model bears six uncertainties. These are base demand projection, margins by sales channels, (PH)EVs' effect, ICE fuel efficiency improvement, hypermarket gas station's effect as a competitor, and future land price. These are explained below.

4.3.1 Base Demand

During our projection period, the sales volume of our imaginary oil company is designed to be adjusted by base demand trend. With this assumption, we expect to get a general insight into the market although we are dealing with the economics of only one gas station (a small amount of sales volume).

Although its fluctuation is not our concern in this study, base demand is the uncertainty that has the most significant influence on a gas station's economics along with gross margin. For our modeling purpose, we used the bootstrapping method, which is a Monte Carlo simulation (Jorion, 2007). As the first step of the simulation, we calculate demand growth rates for each year from the last 18 years data (1994 to 2011) (KNOC, 2012). After setting up 17 scenarios from the data, we made our simulation tool randomly pick scenarios, 10,000 times for each future year' growth rate estimation. For our simulation, we used @RISK by Palisade Co.. Following Figure 12 shows the result of our projection to 2050. As could be seen in Figure 3, the domestic fuel demand in Korea has, so far, remained stable. Nevertheless, the long-term projection reveals a potentially huge divergence.

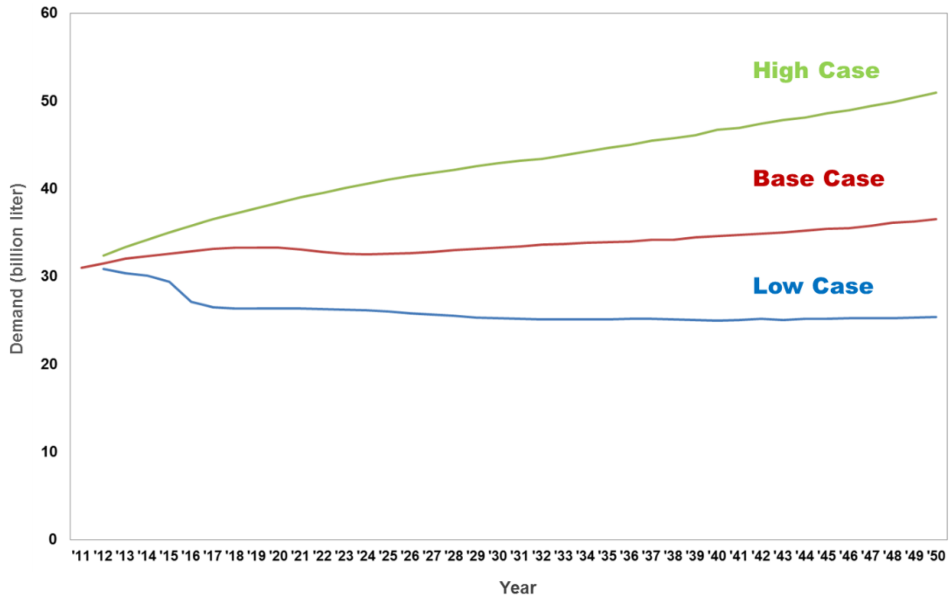

Figure 19: Base Demand Projection Result (Gasoline & Diesel)

4.3.2 Margins by Channel

The second uncertainty to our model is the channel margins. In brief, oil companies' margins in the Korean market consist of the refining and marketing margin. Chapter 2 already laid out a simplified structure of Korean oil companies' margin (Figure 15). This study mainly concerns the change in an oil company's retail profit. Thus, in this paper "margin" refers only to the marketing margin. Selling products at CC involves a huge initial investment and high cost expenditure. In this channel then, an oil company usually wants to sell at a higher price than in other channels. The same logic explains why DC's prices are higher selling through SPOT. Recall that an oil company should pay some of the costs in the contract with a DC dealer.

To create some margin scenarios for each alternative, we used prices from the past six years, representing the maximum available data. Table 5 shows prices of different channels and the margin calculation formula adopted in this model. Based on these data, Monte Carlo simulation was conducted and, for each decision alternative, three possible future margin scenarios were defined; Figure 20 shows the results.

Table 5: Annual Average Price Data and Margin Calculation Formula by Sales Channels (Energy Media, 2012)

Year	Singapore SPOT (A)		Domestic SPOT (B)		Wholesale Price (C)		Pump Price (D)	
	G	D	G	D	G	D	G	D
2006	1.18	0.98	1.22	0.99	N/A	N/A	1.34	1.10
2007	1.22	1.06	1.27	1.05	1.33	1.11	1.37	1.14
2008	1.46	1.41	1.41	1.34	1.44	1.34	1.52	1.45
2009	1.29	1.11	1.34	1.14	1.39	1.18	1.44	1.25
2010	1.37	1.21	1.45	1.27	1.47	1.27	1.53	1.35
2011	1.57	1.43	1.65	1.49	1.66	1.50	1.73	1.57

CC Gross Margin = (D) – (A)

DC Gross Margin = (C) – (A)

SPOT Gross Margin = (B) – (A)

* price unit = USD/liter

* Foreign Exchange Rate (KRW/USD) = 1114.512 (last 5 year’s average)

* G: gasoline / D: diesel

* The data is the result of sample survey.

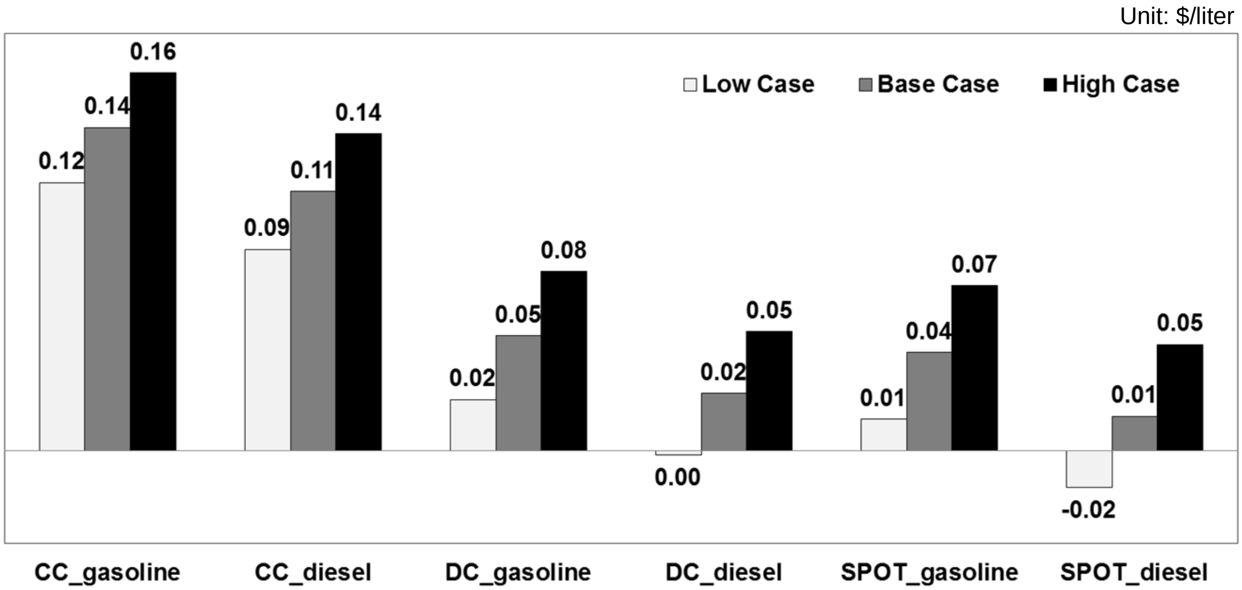

Figure 20: Simulation Result of Gross Margins by Channels

4.3.3 (PH)EVs' Oil Displacement Effects

The model's third uncertainty concerns the degree to which demand will be affected by (PH)EVs. To define low, base, and high cases of (PH)EVs' effect on demand, we used three market penetration scenarios. These were discussed in Chapter 3, where the data simulated were vehicle numbers. Thus, to convert this data into a demand effect, an additional step was required. Table 6 shows the formulas that explain this converting process.

Table 6: Oil Displacement Effect Calculation

- $(PH)EVs'\ Net\ Share = \dfrac{New\ (PH)EVs\ Sales - Scrappage\ Number}{Total\ Registered\ Vehicle\ Number}$

- *Total Fuel Usage without (PH)EVs*

  = Total Registered Vehicle Number × Average Fuel Efficiency × Average Driving Range

- *Total Fuel Usage with (PH)EVs*

  = ((PH)EVs' Net Share × Fuel Efficiency of (PH)EV + Regular ICE Share × Fuel Efficiency)

  × Total Registered Vehicle Number × Average Driving Range

- *(PH)EVs' Oil Displacement Effect*

  = Total Fuel Usage without (PH)EVs – Fuel Usage with (PH)EVs

4.3.4 Fuel Efficiency Improvement

ICE's potential fuel efficiency improvement, the fourth uncertainty, is presumed to have a significant effect on oil demand. Many countries have mandates requiring the average fuel economy of auto manufacturers' production to be at a certain point by a certain time. The Korean government is no exception. It has called for the average fuel efficiency of new cars to be from 14.1km/liter in 2011 to 17km/liter in 2015 (Green Growth Committee, 2012). Numerous technologies can improve the fuel economy of ICE. Important factors to increasing fuel economy include reducing vehicle weight and aerodynamic drag and applying advanced engine and transmission technologies (Bandivadekar, et al., 2008). This report adds as factors the increasing adoption of HEVs and clean diesel vehicles. These consume less fuel than regular gasoline ICE.

Granted, fuel efficiency represents an important uncertainty in the business environment of an oil company. Nevertheless, since these are on the ICE technology margins, it is difficult to say they could bring about a fundamental change to the retail oil market. Therefore, instead of considering every single factor, this study analyzed only the historical data and overall projection of fuel economy. Figure 21 shows ICE fuel efficiency improvement scenarios. These were calculated through regression analysis of historical data and a simulation of the government's plan.

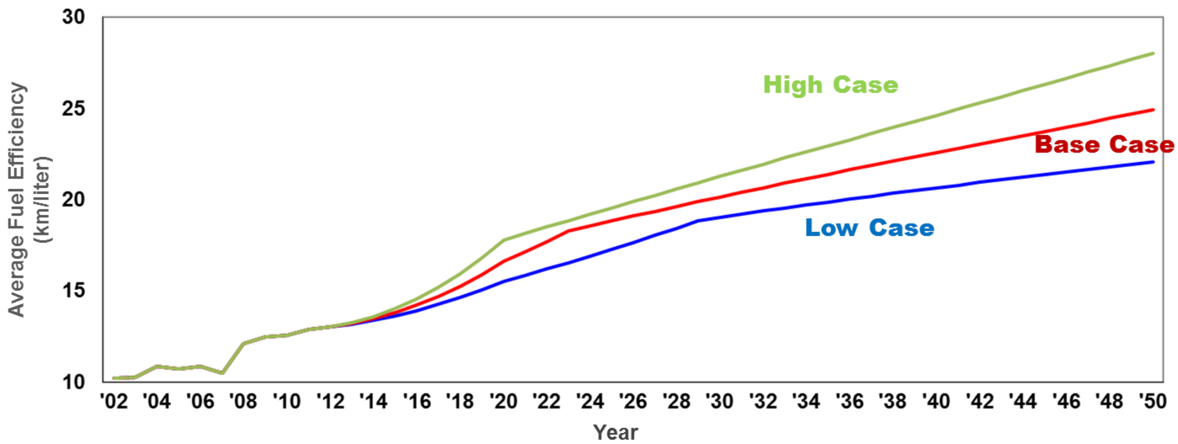

Figure 21: Fuel Efficiency Trend by Case

4.3.5 Government Policies: Hypermarket Gas Stations

A fifth uncertainty present in our model is that of government policies. The Korean government, as noted earlier, continually encourages competition in the retail market (Korean Government TF, 2008). So far, however, its various policies have not proven satisfactory. The exception to this statement is the introduction of hypermarket gas stations.

Oil companies and independent dealers regard hypermarket gas stations, with their low prices and large sales volume, as their biggest threat. For hypermarkets, their main profit comes from their supermarket business. They can afford to view their gas stations as a subsidiary component to their business; it brings more customers into the store. Therefore, they are unconcerned about higher margins at the pump. In fact, they can lower the price to the break-even point. Furthermore, larger sales volumes at hypermarket gas stations strengthen their negotiating power against the oil companies, providing their fuel. This further explains how they can sell fuel so cheaply.

The dominant hypermarket brand, E-Mart, opened its first hypermarket gas station in 2008. Since then, five other sites have been established. Table 7 compares 2011's average pump prices at hypermarket gas stations with those of regular gas stations (in the same local area) (Opinet, 2012). In this study, we analyzed the possible price gap between our imaginary site and a hypermarket in the same price zone from which these data are drawn. According to our simulation result, the price gap could be as much as \$0.05/liter for gasoline and \$0.04/liter for diesel. In the next step, we converted this price gap estimation into the effect on sales of our gas stations. We did so using recent research results on Korean customers' price elasticity of petroleum products demand. According to this study, the price elasticity of gasoline is -1.64 and that of diesel is -0.501 (Kim, 2010).

Table 7: Comparison of Hypermarket Gas Stations' and Regular Sites' Retail Oil Price (Opinet, 2012)

Unit: $/liter, annual average of 2011

No	Average Pump Price				Price Gap	
	Hypermarket Gas Stations		Regular Sites in Local Areas			
	G	D	G	D	G	D
1	1.66	1.56	1.74	1.58	-0.08	-0.01
2	1.69	1.54	1.72	1.57	-0.04	-0.03
3	1.69	1.53	1.72	1.56	-0.03	-0.03
4	1.67	1.51	1.72	1.57	-0.05	-0.05
5	1.69	1.53	1.72	1.57	-0.03	-0.03
6	1.69	1.53	1.72	1.56	-0.03	-0.02
Avg.	1.68	1.53	1.73	1.57	-0.04	-0.03

* G: gasoline / D: diesel

4.3.6 Real Estate Price

The sixth and final uncertainty with our model is the price of real estate. In fact, this factor is one of the more important uncertainties when it comes to Korean oil companies' retail decisions. When an oil company decides to purchase land for a gas station, the NPV of this strategy is affected greatly by the salvage value of the land. Normally, land depreciation is not applied. As Figure 3 shows, land prices in Korea have kept rising. From 2001 to 2010, it rose at an average rate of 3.3% (Onnara, 2012). As Chapter 2 pointed out, an important reason for burgeoning number of gas stations is the steady and sustained growth of real estate value. In this research, we evaluated future scenarios of land price's annual increase with historical data and the Monte Carlo simulation method. The calculated value of the low case was 1.6%, the base case 3.3%, and the high 5.0%.

4.4 Other Assumptions

Table 8: The Value of Constants

Description	Units	Value
FX	KRD/USD	1,114.51
inflation rate	%	3.20%
base site sales volume	mil. liter/yr	2.40
WACC	%	10.00%
tax rate	%	24.20%
CC_land	USD million/site	2.00
CC_buildings	USD million/site	0.20
CC_facilities	USD million/site	0.03
OpEx_CC	$/liter	0.04
OpEx_DC	$/liter	0.02
DC_facilities	USD million/site	0.02
variable_transport cost	$/liter	0.01
variable_membership cost	$/liter	0.00
variable_credit card commission	%	1.50%
gasoline portion (CC)	%	70.00%
gasoline portion (DC)	%	50.00%
gasoline portion (SPOT)	%	30.00%
DC sales ratio	%	70.00%
SPOT sales ratio	%	50.00%
current fuel efficiency	km/liter	12.89
strategic value of CC	$/liter	0.00
strategic value of DC	$/liter	0.00
strategic value of SPOT	$/liter	0.00

Table 8 shows other assumptions in our decision model. We used 10% as a discount rate for the NPV calculation and 3.2% as the inflation rate for the annual cost increase estimation. Sales volumes for each channel, as mentioned before, differ. In our model, of CC's total sales volume, we assumed DC to have 70% and SPOT 50%. No perfect data source exists for these numbers, so we took these percentages from some interviews and sample research (Seo & Kim, 2011). Many Korean gas stations sell, in addition to gasoline and diesel, kerosene; here, however, we consider only gasoline and diesel sales. In addition, we assumed that of the total sales volume each sales channel had a different portion of gasoline; CC's was 70%, DC's 50%, and SPOT's 30%.

4.5 Model Results

The main purpose of this study is to evaluate (PH)EV's effect on an oil company's network decision and to discern whether the effect is meaningful enough to change the frame of market. With the developed uncertainty scenarios and other assumptions in previous sections, we conducted, for the three alternatives, decision analysis. The main simulation software used for this study was DPL by Syncopation Software. Initially, we tested the BAU (Business As Usual) case and then in sequence examined the cases with technology and policy issues. Using the Monte Carlo simulation method, the model was designed to repeat, 10,000 times, the selection of different combination of uncertainties. The probability distribution of uncertainty cases was defined as a discrete distribution and, by applying "Swanson's 30-40-30 rule," we assigned the respective weights of 0.3, 0.4, and 0.3 were assigned to "Low (P10)", "Base (P50)" and "High (P90)" cases; 0.3P10+0.4P50+0.3P90 is known to provide "a good approximation to the mean values for modestly skewed distributions" (Hurst, et al., 2000).

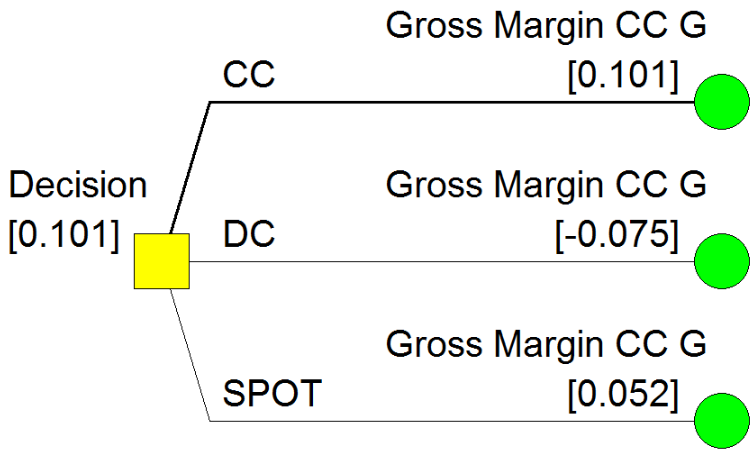

Figure 22: Policy Tree under BAU Assumption

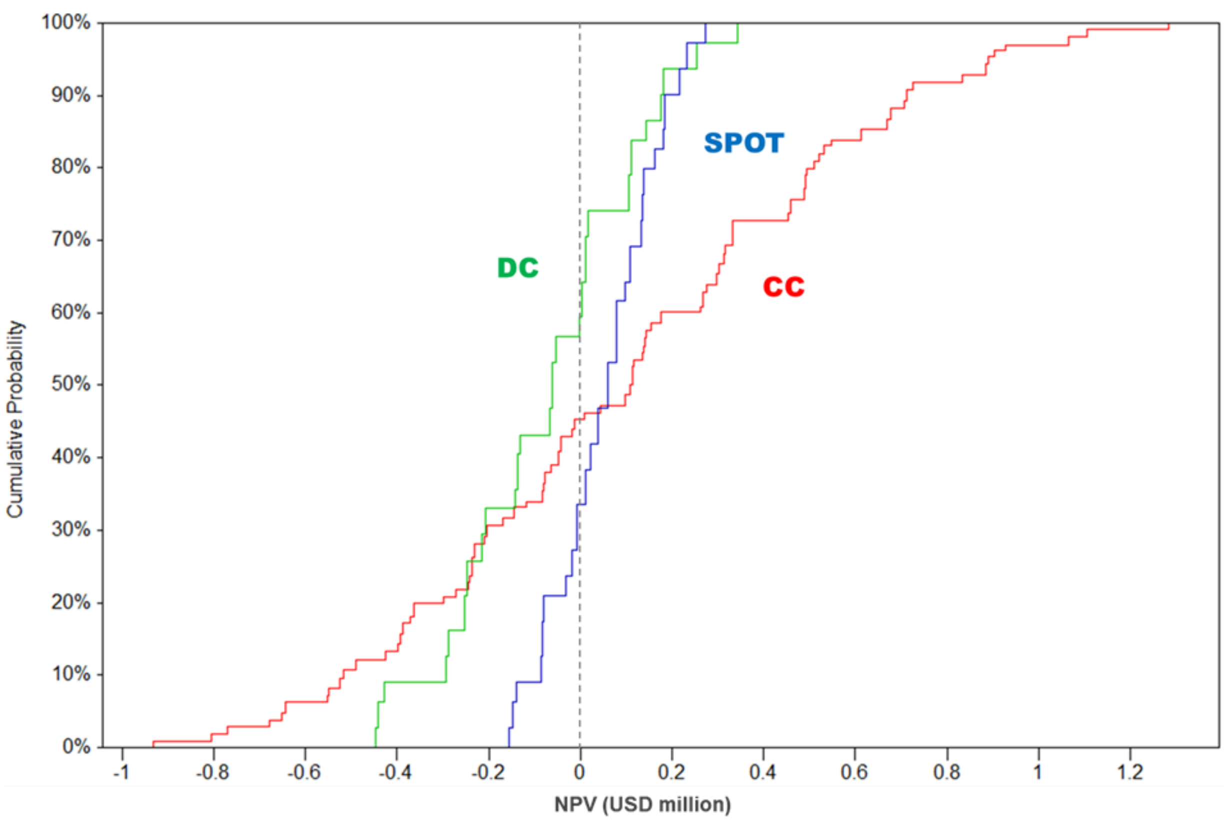

Figure 23: Risk Profiles of Decision Alternatives under BAU Assumption

Figure 22 illustrates that on the BAU assumption CC is the most profitable option and DC the least. Figure 23 shows the risk profiles of each strategic alternative. Cumulative probability function of CC has a much gentler slope than the alternatives. This can be explained in two ways. First, because CC's sales volume is larger than other options, the effects of base demand and margin variation happen, in the CC case, to be larger. Secondly, CC requires initial investment for land, building, and other facilities. Therefore, the change in land price has a not negligible influence on the NPV of the CC alternative. The tornado diagram below shows each uncertainty variation's effect on NPV.

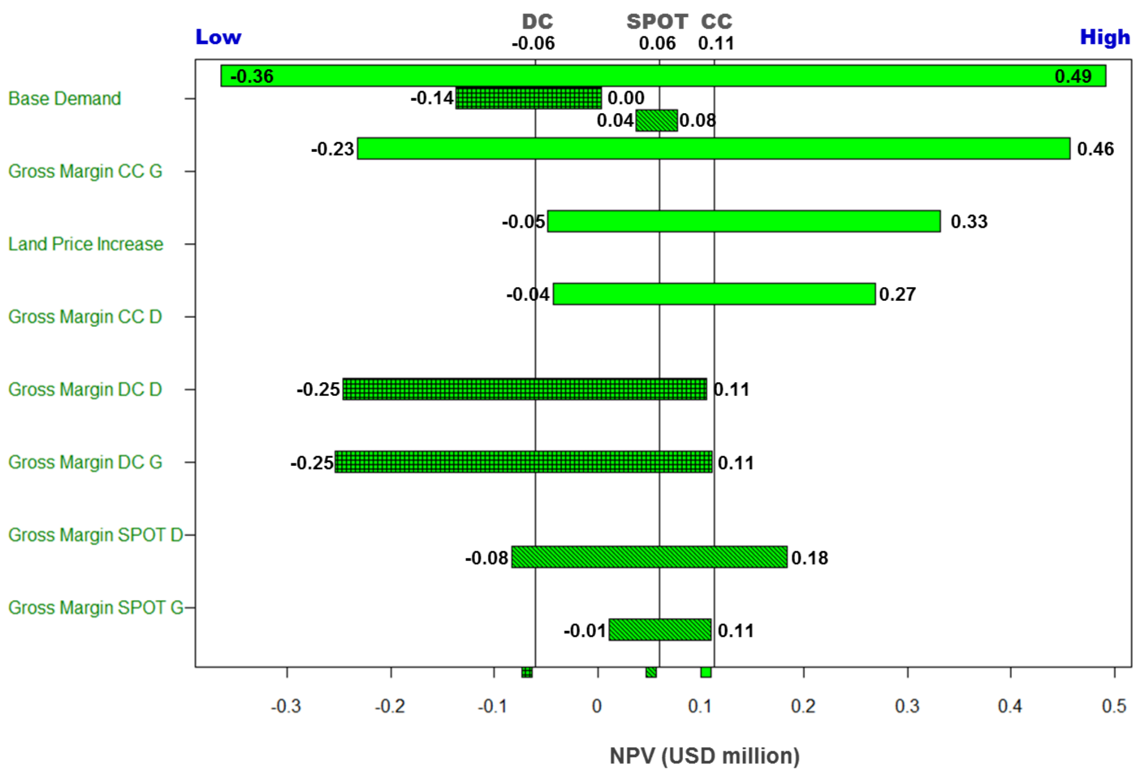

Figure 24: Tornado Diagram on BAU Assumption

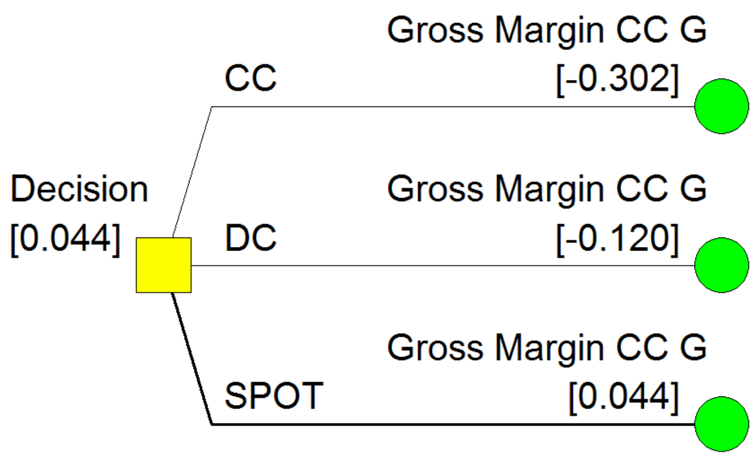

Figure 25: Policy Tree with Technology and Policy Effects

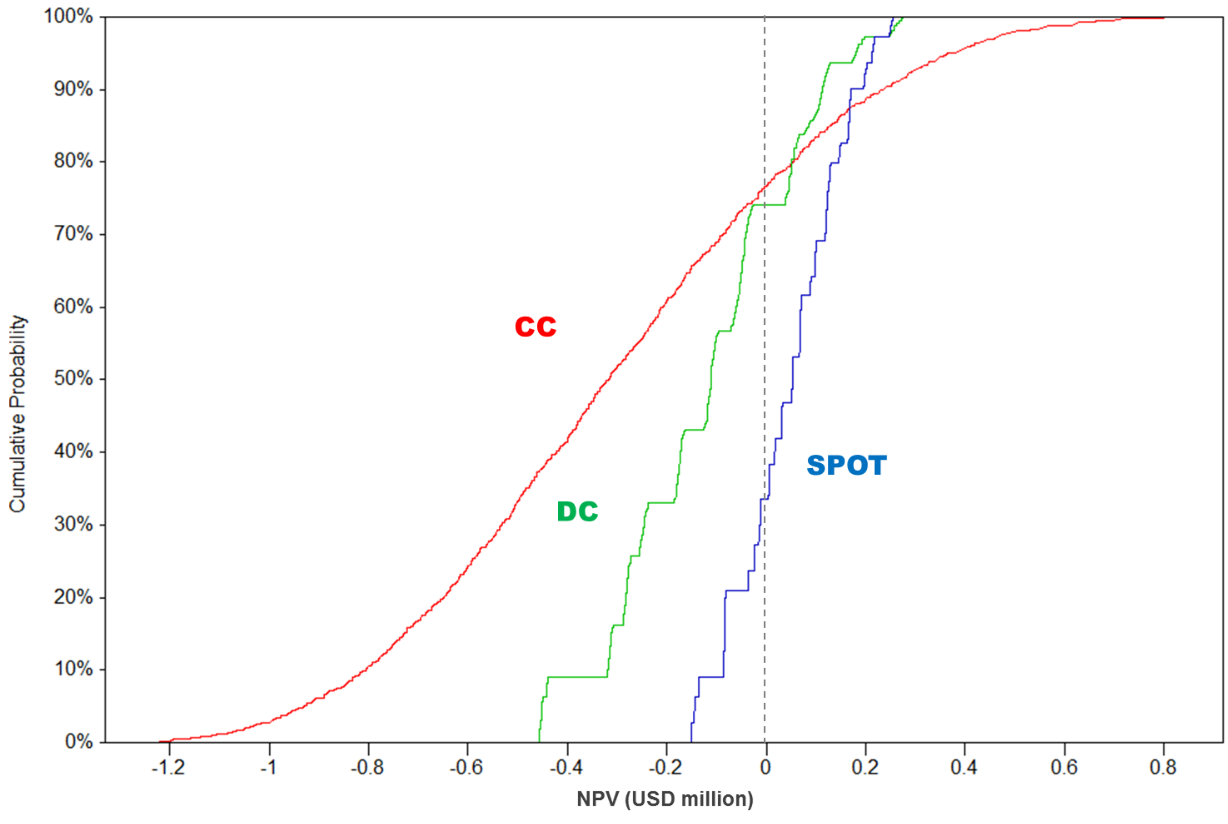

Figure 26: Risk Profiles for Decision Alternatives with Technology and Policy Effects

Figure 25 shows the simulation result; it includes the effects of (PH)EVs, of improvements in ICE fuel economy, and of the sale encroachment of hypermarket gas stations. What is remarkable here compared to the previous simulation is the decline of CC's economics. This outcome is also observed in Figure 26. We can see that CC NPV's cumulative probability curve moved to the left side of the graph, reflecting economic degradation. The tornado chart for this case (Figure 27) gives us some clues. We can see that uncertainties having greater influence on CC than on DC and SPOT options are those of ICE fuel efficiency improvement and (PH)EV adoption; hypermarket encroachment has a trivial effect. This phenomenon seems to be explained by the gasoline portion of CC's total sales. Since new vehicle technologies mainly displace gasoline sales, a CC having a high gasoline sales ratio, is more seriously affected by such technologies than are the alternatives.

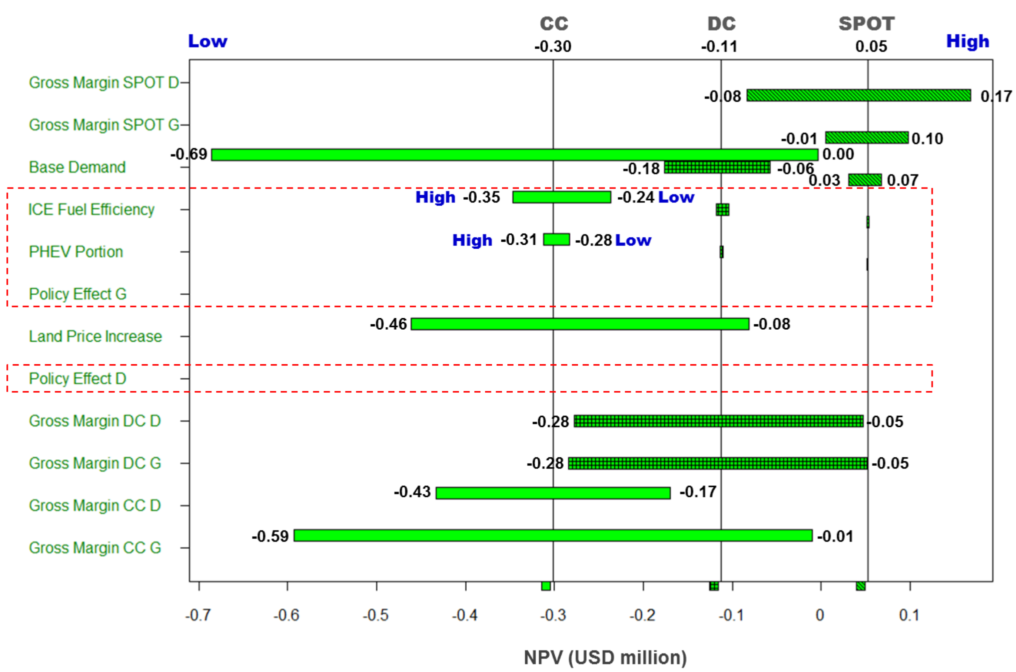

Figure 27: Tornado Diagram with Technology and Policy Effects

The modeling results verified one of this researches hypotheses—(PH)EV diffusion can alter oil companies' decisions; initially the most preferred alternative, CC becomes the most unprofitable option. We might interpret this outcome as implying that the more uncertain the market is, the smaller investment brings greater profit.

The second question this study posed was how significant the effect of (PH)EVs will be. That is, the study tried to verify whether (PH)EVs' effect could change the current retail oil market structure. Figure 28 shows the change in CC gas stations economics before and after considering technology effects. CC's profit clearly suffered. However, no clear evidence emerged that this really means a fundamental change to the market. As seen in Figure 27, (PH)EVs' effect is smaller than that of other uncertainties. If we consider already existing gas stations which need no huge investment, we can foresee some merit, despite (PH)EVs' market penetration, in keeping a gas station network in Korea's market.

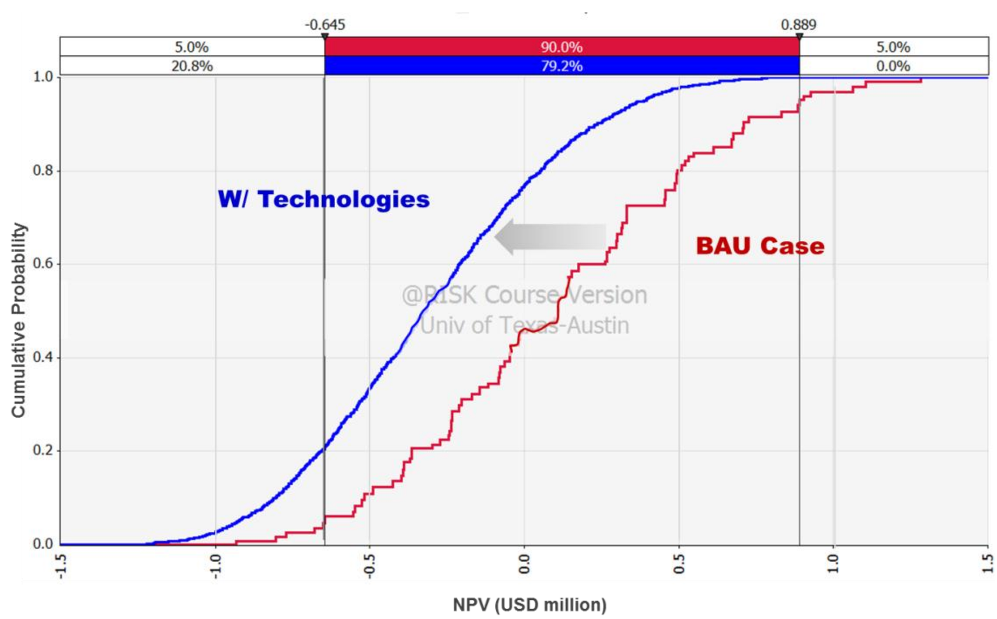

Figure 28: CC Economics Change

Additionally, this study conducted VOI (Value of Information) analysis. We can see the values of perfect information about each uncertainty in BAU case are positive (Figure 29): an oil company's decision is actually changed by the information.

	VOI*(USD million)	CE*(USD million)		probability	alternative selected	NPV(USD million)
wo/ Perfect Infromation		0.101			CC	0.101
			"L"	0.3	SPOT	0.031
w/ Perfect Information_base demand	0.113	0.214	"B"	0.4	CC	0.130
			"H"	0.3	CC	0.509
			"L"	0.3	SPOT	0.052
w/ Perfect Information_margin_CC	0.134	0.235	"B"	0.4	CC	0.101
			"H"	0.3	SPOT	0.595
			"L"	0.3	CC	0.101
w/ Perfect Information_margin_DC	0.044	0.145	"B"	0.4	CC	0.101
			"H"	0.3	DC	0.247
			"L"	0.3	CC	0.101
w/ Perfect Information_margin_SPOT	0.038	0.139	"B"	0.4	CC	0.101
			"H"	0.3	SPOT	0.229
			"L"	0.3	SPOT	0.052
w/ Perfect Information_land price	0.038	0.139	"B"	0.4	CC	0.083
			"H"	0.3	CC	0.302

*** VOI (Value of Information) / CE (Certain Equivalent)**

Figure 29: VOI (Value of Information) in BAU case

However, once we consider ICE's fuel efficiency improvement and (PH)EVs' oil displacement effect, VOIs drop to zero. It is because no matter which values the uncertainties have, the oil company's best decision is never changed (Figure 30).

	VOI*(USD million)	CE*(USD million)	alternative selected
wo/ Perfect Infromation		0.044	SPOT
w/ Perfect Information_base demand	0.000	0.044	SPOT
w/ Perfect Information_margin_CC	0.000	0.044	SPOT
w/ Perfect Information_margin_DC	0.000	0.044	SPOT
w/ Perfect Information_margin_SPOT	0.000	0.044	SPOT
w/ Perfect Information_land price	0.000	0.044	SPOT
w/ Perfect Information_fuel efficiency improvement	0.000	0.044	SPOT
w/ Perfect Information_(PH)EV's oil displacement	0.000	0.044	SPOT
w/ Perfect Information_hypermarket gas station effects	0.000	0.044	SPOT

* VOI (Value of Information) / CE (Certain Equivalent)

Figure 30: VOI (Value of Information) with Technology and Policy Effects

5. Conclusion

This study examined the implications of an oil company's retail decision when facing the uncertainty of (PH)EV market penetration. The paper specifically looked at the network strategies of an imaginary Korean oil company. Because of (PH)EVs' oil displacement effect and the different recharging styles from ICE vehicles, oil companies may need, if (PH)EV's diffusion becomes wide enough, entirely different strategies for their network investment.

The study covers two main topics. The first is estimating, based on recent studies, the (PH)EV's penetration rate. The second is evaluating how such market penetration affects an oil company's network strategy selection. For the first topic, this paper synthesized the forecasting data of recent studies; with this data plugged into a technology diffusion model, we approximated three scenarios. According to this study's base case, (PH)EVs' market penetration will reach, in 20 years, about 11%.

For the second topic, this study built a probabilistic decision model. This model was designed to include ICE fuel economy improvement, the sales encroachment of hypermarket gas stations and other uncertainties aside from (PH)EV's effect. This study found, after simulation, that alternative transportation technology can affect an oil company's network decision. Especially in the more uncertain situation, the CC option, with its need for heavy initial investment, was not preferred. However, this study failed to establish confidence in the significance of the effect's scale. After considering the effect of this technology, an oil company's profit was seen to shrink, yet the loss failed to look so serious as to justify an oil company's relinquishing of its current network.

However, as long as the business environment keeps changing, oil companies should continually evaluate their strategy. The methodology and modeling used in this paper might be applied for this purpose with oil companies. So far, only a few studies have been based on real historical data of (PH)EVs. This paper has the same problem. While its focus is the Korean market, it could not reflect that market's real data of (PH)EV adoption because none yet exists. I expect that as more (PH)EVs are sold, a more accurate study will be conducted and overcome this study's limitation.

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